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Top-Down/Bottom-Up Method For Identifying a Set of Voltage Stability Preventive Controls

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***Abstract*— In this work, a novel method for choosing a global set of preventive controls for voltage stability analysis is developed. The method depends on top-down and bottom-up approaches to obtain the set of controls according to voltage stability sensitivity analysis. At first, the sensitivities of the voltage stability margins of network buses to preventive controls are obtained. The average of the sensitivities referred to each preventive control is then calculated, which gives an indicator about how each preventive control can improve the voltage stability margin of power system. The average is done over the sensitivities of different critical buses located at different locations. The two approaches (top-down and bottom-up) are then performed on the averaged sensitivities to choose a set of the most efficient controls. The proposed method is able to simultaneously eliminate the impact of system contingencies on network buses. The proposed method is checked on the IEEE 39 bus network. The results demonstrate the accuracy and the validity of the proposed method for control selection.**

Keywords*— *Voltage stability; Preventive Control; Controls Identification; Controls Coordination; Top-Down and Bottom-Up approaches.

I. Introduction

Voltage instability is a critical issue for power system operators. Several blackouts occurred due to voltage instability or collapse [1]. Thus, voltage stability assessment is an important task to avoid system failure.

System contingencies could make the network insecure. Thus, preventive measures have to be made to eliminate the impacts of the contingencies on system nodes and maintain the system secure. In general, loading (or voltage stability) margin is used to assess the system stability. This margin is usually obtained by taking the difference between the maximum loadability point and the current operating point.

Several approaches have been proposed to select the preventive or corrective controls for power system [2]-[4]. Some methods solve the problem using optimization programming problems [5]. However, one of the disadvantages of this kind of methods is that many preventive controls have to be activated for preventive control. Solution infeasibility is another disadvantage. Therefore, optimization methods cannot be used in large-scale power systems.

Some methods are based on sensitivity analysis to select the most efficient controls [6]-[12]. Sensitivity analysis, in this context, represents the sensitivity of voltage stability margin (i.e. maximum loadability point) to the control variables. Network operators can then select the one (or more) preventive control according to the sensitivity values.

Generally, only one critical bus (i.e. pilot bus) is considered for analysis. However, considering only one bus is not enough to ensure that the system is secure. This is due to fact that the sensitivity analysis cannot provide the exact relation between the preventive controls and network buses. There is possibly another critical bus in the system with a lower voltage stability margin. Thus, it is necessary to consider a set of critical buses.

This work presents a novel approach for preventive control selection in power system. Top-down and bottom-up approaches are used to sequentially choose the set of most effective controls according to voltage stability sensitivity analysis. The method considers several critical buses, not only one bus for sensitivity analysis. The selected controls are able to simultaneously eliminate the impacts of system contingencies on the critical buses. By this approach, only the minimum number of preventive controls are identified and coordinated with each other. The calculations of this method are simple and fast and thus it is applicable for online applications.

It is worth mentioning that the objective of this work is not to obtain the optimal solution, but gives a set of the most efficient preventive controls. By this method, the number of preventive controls used in problem solution will be reduced.

The rest of this work is as follows. Section II discusses the sensitivity analysis method used in this work. Section III presents top-down and bottom-up approachs for identifying a set of the preventive controls in power systems. Section IV presents the results and discussion. Section V presents the conclusions.

II. SENSITIVITY ANALYSIS

For any power system, the nodal current can be expressed in the terms of system voltages and admittances as:

$$\begin{bmatrix} I_G \\ -I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (1)$$

Where I_G and I_L denote the generator and load currents, respectively. V_G and V_L are generator and load voltages, respectively. Y_{GG}, Y_{GL},Y_{LG}, Y_{LL} are submatrices of the system admittance matrix Y.

According to (1), load voltage at node i is calculated as:

$$V_{L,i} = [(-{Y_{LL}}^{-1}\, Y_{LG})V_G\,]_i - Z_{LL,ii}I_{L,i} - \sum_{j\neq i} Z_{LL,ij}I_{L,j} \quad (2)$$

Where $Z_{LL} = {Y_{LL}}^{-1}$. $Z_{LL,ii}$ (or $Z_{LL,ij}$) is the ii[th] (or ij[th]) element of Z_{LL}. Accordingly, the equivalent impedance of node i is obtained as:

$$Z_{eq,i} = Z_{LL,ii} + \sum_{\substack{j \in L \\ i\neq j}} Z_{LL,ij}\frac{I_{L,j}}{I_{L,i}} \quad (3)$$

According to Thevenin impedance theorem, the voltage stability margin δ can be found as:

$$\delta_{\mathrm{i}} = \frac{|Z_{L,i}|-|Z_{eq,i}|}{|Z_{L,i}|} \quad (4)$$

Where Z_L denote the load impedance:

In this work, the sensitivity analysis method developed in [15] is used to find the sensitivity of δ_{i} to the change in the preventive controls.

If it is assumed that α_{ik} is the sensitivity of i[th] voltage stability margin to k[th] control variable, the average of sensitivity of multiple critical buses to a preventive control (α_k) can be expressed as:

$$\alpha_k = \frac{\alpha_{1k}+\alpha_{2k}+\cdots+\alpha_{Mk}}{\mathrm{M}} \quad (5)$$

Where M is the number of the multiple buses. It is worth mentioning that other factors, like cost, can be also considered in the average sensitivity formula.

The average sensitivity illustrated in (5) can be used to select a set of preventive controls for voltage instability mitigation. The next section will present a novel technique for control selection.

III. IDENTIFYING THE GLOBAL CONTROL GROUP

It is necessary to develop identification methods to choose a group of preventive controls to simultaneously mitigate the impacts of system contingencies on network buses. In this work, two algorithms are selected to choose the control group. The algorithms are well-known as top-down and bottom-up methods. They can treat system data and organize the knowledge. They are widely used in different fields. One of the applications of both methods can be found in [16]. Both algorithms are fast. This is due to the fact that they have a low computation effort for the analysis. Thus, they can be used for real-time applications.

In the top-down approach, the main problem is separated into multiple smaller subproblems. These subproblems can be also separated to simpler subproblems to make the problem easy to understand. In this approach, each subproblem is separately resolved for analyzing the global problem.

In the bottom-up approach, the procedure is done in an inverse way for top-down approach. Multiple rules can be defined for the individual behaviors through this approach. They are then integrated into the global problem. The process direction can be understood from Fig.1.

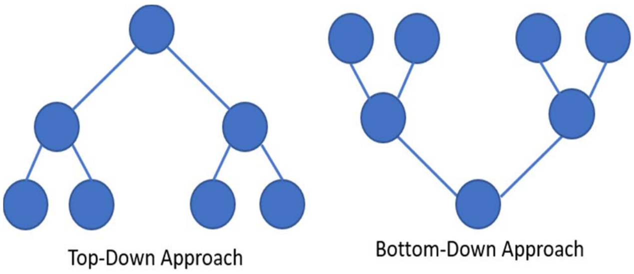

Fig.1: Top-Down approach and Bottom-Down approaches

The individuals in top-down approach are combined in a way so that they may not communicate well. This could create redundancies in the obtained results. However, this problem can be avoided using the bottom-up method. Indeed, bottom-up approach depends on information hiding in analyzing the data.

In this study, both methods are used for selecting a set of preventive controls for voltage stability analysis in power systems. The top-down method uses aggregate control to find the set of the control group, which is then assigned to individual preventive controls based on their average sensitivity ranking. The bottom-up method utilizes individual preventive controls to test the process of the voltage stability assessment.

For our study, the top-down approach sequentially selects the preventive controls, starting from the one with highest average sensitivity. The process continues until the contingency is mitigated. This means that the top-down approach chooses the most efficient preventive controls. However, the obtained group of controls may involve excessive controls. To avoid the useless controls, a bottom-up approach is also used.

A. Top-down phase approach

In this work, it is assumed that Γ is a vector of voltage stability margins of the critical buses, i.e., $\Gamma = [\Psi_1, \Psi_2,.., \Psi_N]$ and φ is the group of the most efficient preventive controls. As we mentioned before, this approach finds the control group φ by selecting the preventive controls having high sensitivities. To predict the effect of the selected controls on the voltage stability margins, the margins in Γ is increased by the sensitivity values of the preventive controls. The procedure for the top-down approach in choosing the control group is presented in the flowchart shown in Fig.2. Where N_c is number of preventive controls and k denotes a preventive control.

B. Bottom-up approach

The bottom-up approach is used to refine the results found using the top-down approach. This can be achieved by evaluating all the obtained preventive controls, starting from the last selected ones (i.e. opposite direction for top-down approach), and removing the useless ones. The effective of this step can be seen if negative factors (like cost) are involved in the analysis. For this approach, it is assumed that £= [Ψ_1, Ψ_2,..] is a vector of the voltage stability margins obtained by top-down approach. To predict the effect of the eliminated preventive controls on the voltage stability margins, the margins in £ is reduced by the sensitivity values of the preventive controls.

The preventive controls are considered unnecessary, if its neglecting from the set φ will not decrease the margins to a value less than a threshold value. The set φ′ is the control group obtained by bottom-up approach. The procedure for the bottom-up approach in refining the control group is presented in the flowchart presented in Fig.3. Where N'_c is the control variables number in the group φ, and k denotes for a preventive control in the set φ.

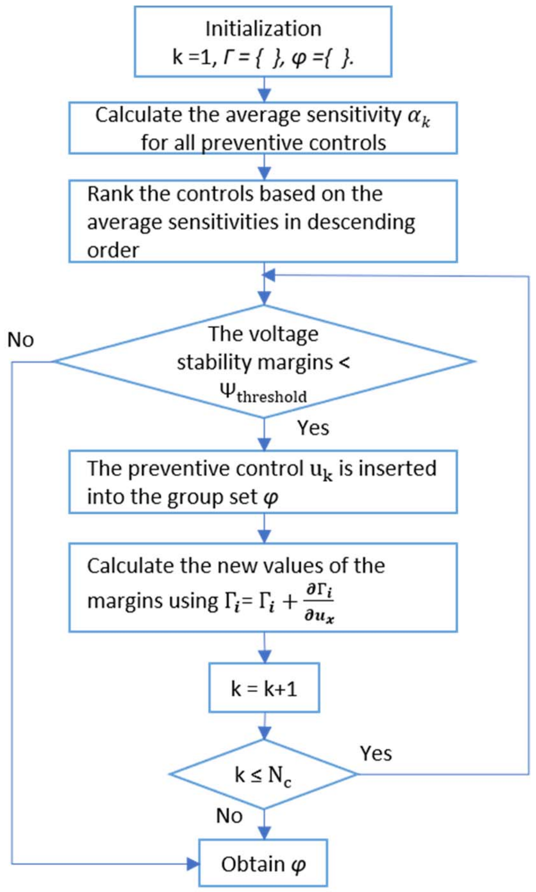

Fig.2: A flowchart of the top-down approach for control selection

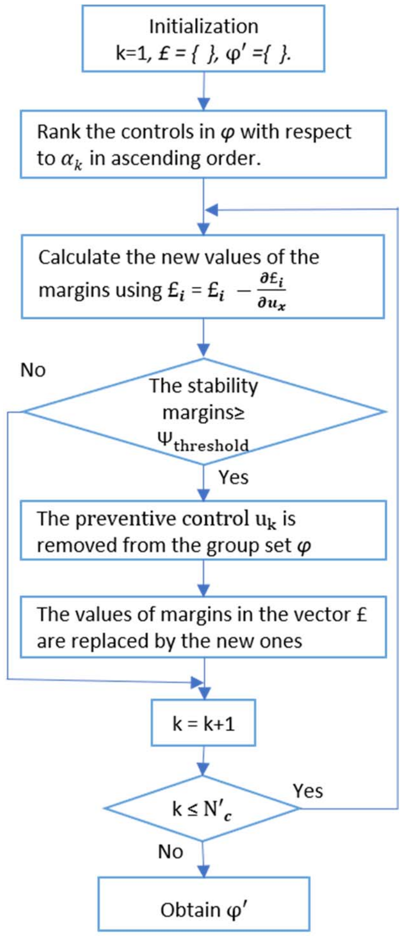

Fig.3: A flowchart of the bottom-up approach for control refining.

IV. Simulation Results and Discussion

In this paper, IEEE 39-bus network is used to check the correctness of the presented selection control method. The system topology is presented in Fig.4. The slack bus (bus 39) will not be considered in the control selection. Three capacitors (each with rating of 10MVar) are assumed to be installed at three buses (5,15, and 27). To make the system more stressed, the load demands are increased to 1.4 of their normal values. The system information can be found in [17].

In this study, the active powers by the nine generators and the three shunt capacitors are used for control selection. The control parameter of each generators represents 0.1 p.u of its own power while the control parameter of the capacitor represents one step control action (50 KVAR). The same strategy can be implemented for other types of preventive controls.

One contingency is made on the network by tripping the line 3–18. At first, the average sensitivity for each preventive control is calculated. Based on these average sensitivities, the top-down and bottom-up approaches are implemented to obtain the set of the preventive controls.

Table I shows some of those margins. In this work, it is assumed that five buses (1, 8,15,16 &28) are critical buses. The margins are less than the threshold value, which is considered to be 0.3 in this study.

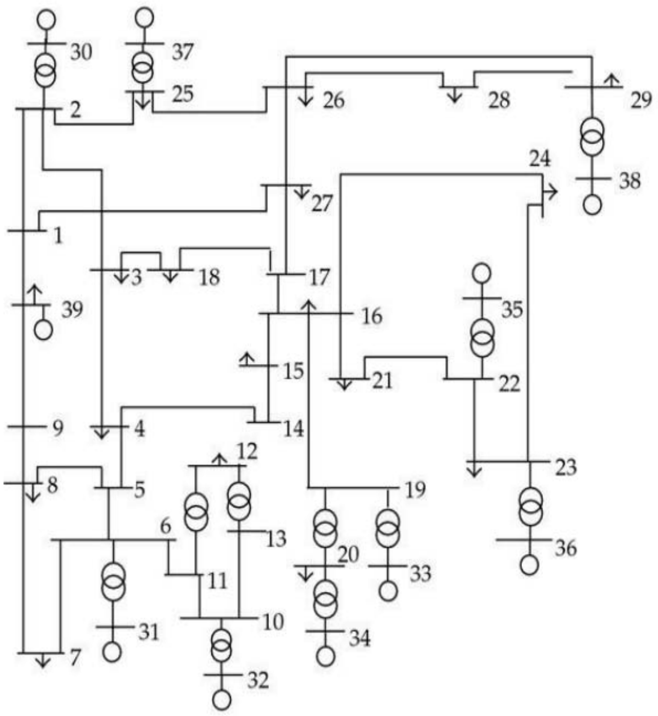

Fig. 4. The IEEE 39-bus system

TABLE I. VOLTAGE STABILITY MARGINES OF SOME CRITICAL NETWORK BUSES

Bus No.	Margin
1	0.242
8	0.231
15	0.224
16	0.220
28	0.244

To calculate the sensitivity of the voltage stability margin of each critical bus to the change in the preventive controls, the sensitivity analysis developed in [15] is used. The sensitivity values are illustrated in Table II. It is worth noting that any sensitivity analysis approach can also be used for this purpose.

To find the effectiveness of each preventive control on voltage stability margin of different load buses, the sensitivities referred to each control are averaged. The average sensitivities are presented in Table III. The results show that the control P_{g38} has the highest average sensitivity and thus it occupies the first rank in the context of the effectiveness on stability margins.

Once the average sensitivities are obtained, the top-down and bottom-up approaches are used to select a set of the preventive controls. The global group has the ability to mitigate impacts of the system contingencies on the critical buses. Table IV shows the selected controls. It is clear that the selection was done based on the ranking obtained in Table III based on the average sensitivities. In this scenario, the preventive controls selected using the top-down approach and the bottom-dup approach are the same. This is due to the fact that no other factors (like cost) are included in the analysis.

TABLE II. SENSITIVITY VALUES OF VOLTAGE STBILITY MARGINS TO PREVENTIVE CONTROL

Control	Bus No.				
	1	8	15	16	28
P_{g30}	0.2220	0.2217	0.2226	0.2228	0.2229
P_{g31}	0.2611	0.2618	0.2617	0.2619	0.2605
P_{g32}	0.2693	0.2690	0.2692	0.2694	0.2696
P_{g33}	0.2158	0.2157	0.2161	0.2163	0.2161
P_{g34}	0.2434	0.2432	0.2435	0.2437	0.2417
P_{g53}	0.2722	0.2719	0.2727	0.2729	0.2718
P_{g36}	0.2854	0.2855	0.2855	0.2857	0.2854
P_{g37}	0.2910	0.2910	0.2910	0.2912	0.2933
P_{g38}	0.2944	0.2944	0.2945	0.2947	0.2960
C_5	0.2761	0.2729	0.2762	0.2764	0.2804
C_{15}	0.2582	0.2572	0.2578	0.2580	0.2598
C_{27}	0.2239	0.2239	0.2242	0.2244	0.2266

TABLE III. THE AVERAGE SENSITIVITY OF EACH PREVENTIVE CONTROL (α_k)

Control	α_k
P_{g30}	0.2224
P_{g31}	0.2614
P_{g32}	0.2693
P_{g33}	0.2160
P_{g34}	0.2431
P_{g53}	0.2723
P_{g36}	0.2855
P_{g37}	0.2915
P_{g38}	0.2948
C_5	0.2764
C_{15}	0.2582
C_{27}	0.2246

TABLE IV. THE SELECTED PREVENTIVE CONTROLS USING TOP-DOWN AND BOTTOM-UP METHODS

Selected Controls	Rank
P_{g38}	1
P_{g37}	2
P_{g36}	3
C_5	4

To show how the selected preventive controls can mitigate the contingency impacts, the voltage stability margins of the critical buses are recalculated after triggering the selected preventive controls. Table V compares the stability margins obtained before and after applying the selected preventive controls. It is clear that those controls were able to improve the margins to a value greater than the threshold value.

TABLE V. ESTIMATED STABILITY MARGINS WITH ACTIVATION THE SELECTED CONTROLS

Bus No.	Old Margin	New Margin
1	0.242	0.315
8	0.231	0.311
15	0.224	0.309
16	0.220	0.304
28	0.244	0.316

It is worth mentioning that loading power through line 3-18 is high. Thus, line 3-18 tripping was selected to be the contingency for this work. However, the same analysis can be performed during other contingencies.

V. CONCLUSIONS

In this study, an identification approach to obtain a set of preventive controls for fast voltage stability analysis in power systems. The method employed the top-down and up-bottom methods to choose the most efficient controls. By this method, the control group can eliminate the impacts of system contingencies on network buses.

Simulation was made on the IEEE 39-bus system. The controls are successfully combined based on their effectiveness to eliminate the contingency impacts. After activation the selected controls, the voltage stability margins are successfully increased above a threshold value. Thus, the presented approach can help system operators to select only the required number of preventive controls for voltage stability improvement.

Our further work is to involve several factors (like cost) in the analysis and to examine the presented method on a large-scale power networks with different types of preventive controls.

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